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Nutrient stock in soil and trees in a secondary forest provided for shifting cultivation [1]

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Abstract: In South Brazil slash and burn plays a major role for great number of small farmers. However, there is almost no fertilization with mineral fertilizers to compensate the nutrient loss. The aim was to assess the ecological risks. An inventory of the nutrients in the biomass and the soil was done and the potential loss by burning was calculated. Nutrient input by precipitation was measured weekly to estimate the compensation of nutrient losses by atmospheric input. The nutrient status of the ecosystem was on a high level. It was far away from the status of natural rainforests on Ferralsols in the humid tropics. Assessing the ecological risk by a worst case scenario a twofold repetition of slash and burn would empty almost the total stock of exchangeable Mg in the soil. However, considering the real situation after practicing slash and burn for more than 100 years there is no indication that this is real scenario. Obviously the nutrient loss is smaller and a recuperation of the ecosystem occurs by atmospheric input and weathering of primary silicates. For to maintain sustainability it is recommended to provide a recovery time of at least some decades. Nutrient loss could be strongly reduced if branches would be left in the system and biomass extraction was restricted to stemwood. It would be helpful if magnesium loss could be partly compensated through liming or magnesium fertilizers.

Key words: Nutrient balance; Native forest; Slash and burn; Ecological risks.

Estoque de nutrientes no solo e nas árvores de uma floresta secundária proveniente de agricultura migratória

Resumo: No Sul do Brasil o corte e queima de capoeiras tem um papel importante para um grande número de pequenos agricultores. No entanto, não há quase nenhuma adubação com fertilizantes minerais para compensar a perda de nutrientes. O objetivo do trabalho foi avaliar os riscos ecológicos nutricionais em um fragmento de floresta Estacional Subtropical proveniente de um sistema de agricultura migratória. Para isso, um inventário dos nutrientes na biomassa e no solo foi feito e a perda potencial de queima foi calculado. A entrada de nutrientes através da precipitação foi medido semanalmente para estimar a compensação das perdas de nutrientes por entrada atmosférica. O estatus de nutrientes no ecossistema estava elevado, bem acima do estatus de florestas nativas em Latossolos nos trópicos úmidos. Avaliando o risco ecológico de uma dupla repetição do sistema de corte e queima, que seria um caso de pior cenário, este quase esgotaria o estoque total de Mg trocável no solo. No entanto, considerando a situação real, depois de praticar corte e queima por mais de 100 anos, não há nenhuma indicação de que este é o cenário real. Obviamente, a perda de nutrientes é menor, e uma recuperação do ecossistema ocorre pela entrada atmosférica e intemperismo de silicatos primários. Para manter a sustentabilidade recomenda-se garantir um tempo de recuperação de pelo menos algumas décadas. A perda de nutrientes pode ser reduzido fortemente se os galhos fossem deixados no sistema e a extracção da biomassa for restrita somente o fuste. Seria muito proveitoso se a perda de magnésio fosse compensada pelo menos em parte, pela calagem ou adubação com fertilizantes com magnésio.

Palavras-chave: Balanço de Nutrientes; Floresta Nativa; Corte e queima; Riscos Ecológicos.

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Introduction

Shifting cultivation is practiced on large areas all over the world and it is the source of livelihood for more than 300 million. people (BRADY, 1996). Depending on the region the site conditions for this kind of land use are differing in a broad range including sites of the humid tropics, subtropics and moderate climates. Great differences occur regarding to the climate, the geomorphology and the soil properties. Thus, for an assessment of the sustainability a differentiated consideration is required.

In Rio Grande do Sul, South Brazil, for a great number of small farmers shifting cultivation plays an important role. For most of them it is the only income and it is practiced since more than one century by the European immigrants, predominantly. Cutting mostly small parcels it has shaped the mountainous landscape substantially, forming a manifold pattern of pastures, croplands, and different kinds of succession forests. Due to steep slopes shifting cultivation is practiced manually or with a very low degree of mechanization. After cutting the forest, extracting the usable timber, and burning, people usually grow corn, tobacco and all the vegetables and fruits they need for themselves. In general no mineral fertilizers are used (WATTERS, 1971). Thus, after 3-4 years the yield is decreasing to a minimum and the areas are abandoned. Within a few months the area is covered totally with a shrub vegetation changing after a few years to a succession forest. In former times the time for a full cycle until the next clear cut was carried out was between 10 and 30 years.

At first view this practice seems to be sustainable and from the experience practicing shifting cultivation more than one century there is no apparent indication on a severe soil degradation. However, clear-cutting, burning, and the following harvesting of crops are generally associated with considerable ecological risks, such as loss of soil and fertility. It is well known that soil erosion and nutrient losses may occur and could cause a site degradation especially with short rotation periods. Accordingly, some years ago shifting cultivation in Rio Grande do Sul was assessed as a non-sustainable kind of land use and it was prohibited by the government. However, since this practice was stopped by law and clear-cut was restricted to stands younger than 3 years the rotation was accelerated and the time for an ecological recovery was shortened.

During the last years a very strong discussion aroused between the rural population, environmental activists and the government, respectively. This study aims to focus on total ecosystem nutritional balance; it was based on an estimation of the potential nutrient loss after cutting and burning of the vegetation.

Material and methods

The site is located in Itaara (6.731.500 N; 233.000 E) in Serra de São Martinho on the Planalto Médio in Rio Grande do Sul, Brazil (Figure 1). The elevation is 400 m above sea level. For 2005 and 2006 mean precipitation totaled to 1290 mm/yr. The mean annual temperature (2003-2006) is 19,6 °C.

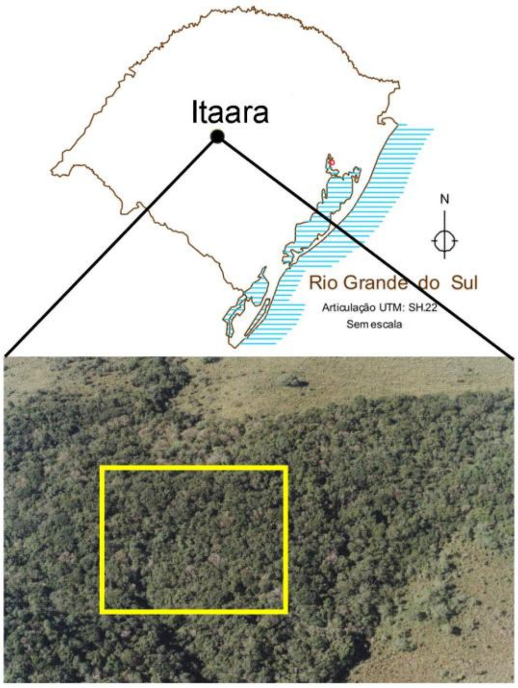

Figure 1 – Location of the city of Itaara and the experimental area in the State of the Rio Grande do Sul, Brazil.
Figura 1 –Localização do município de Itaara e da área experimental no estado do Rio Grande do Sul, Brasil.

Soil type has been classified as a Neosolo lithico eutrofico (STRECK et al. 2008) or a Cambissol by World Reference Base (WRB), respectively. This type is very widespread in the state of Rio Grande do Sul. With a depth of only 30 to 40 cm the developed part of the soil is rather shallow. The mean stone content (fraction > 2 mm) in the A-horizon is 25%, increasing strongly with soil depth. In the AC-Horizon stone content is 50% and there is an abrupt transition from AC to C horizon consisting of a hard quartzitic sandstone. In both horizons soil structure is subangular blocky. Root intensity is high but it concentrates to the topsoil. The compact hard sandstone prevents a further rooting in deeper parts almost completely.

For soil chemical and physical analysis samples were taken from A and AC horizon in a depth from 0-20 cm and 20-40 cm. After drying samples were separated to fine earth < 2 mm and skeleton. Carbon and nitrogen was measured with a CNS element-analyzer. Cation exchange capacity (CEC) and base saturation were determined according to the method of Trüby and Aldinger (1989). For analyzing total element contents soil material was digested with a mixture of hydrofluoric acid (HF) and nitric acid (HNO_3), plant material with HNO_3, using a microwave digestion unit. Soil texture was determined by a modified sedimentation method of Köhn (SCHLICHTING et al. 1995).

The pH-values (Table 1) are in the optimum range for plant growth and indicate a low soil acidity which is not common for soils on quartzitic sandstones. Organic carbon is on an upper level of forest soils (BLUME et al., 2010). The contents are higher than those found on neighboring sites near São Martinho da Serra (PEDRON and DALMOLIN, 2011). The contents decrease only slightly with the soil depth. The nitrogen contents are also on an upper level (BLUME et al., 2010). C/N-ratio is in the range from 11 to12, indicating an excellent N-status of the soil.

Table 1 – Soil characteristics.
Tabela 1 – Características do solo.

Horizon	Chemical properties					
	Depth	pH	C	N	CEC[1]	Bs[2]
	cm	H_2O	%	mg/g	$mmol_c$/kg	%
A	0-20	5,6	3,7	3,2	125	97
A/C	20-40	5,4	3,0	2,5	124	92
Horizon	Physical properties					
	Depth	Texture %			Bd[3]	Sk[4]
	cm	sand	silt	clay	g/cm³	%
A	0-20	29	65	6	0,92	20
A/C	20-40	24	63	12	0,94	50

[1]CEC: cation exchange capacity; [2]Bs: base saturation; [3]Bd: bulk density; [4]Sk: skeleton (rock fragments, fraction > 2 mm)

With more than 60% silt was the main particle size followed by the sand fraction. In contrast clay contents were rather low. Soil texture was loamy silt having a high field capacity. However, due to high amounts of skeleton field capacity of the total soil is low. For the rootable soil zone it is estimated to 0.06 m³/m³, only.

Regarding to the reference values for Lithosols CEC for both horizons is on a high level (BRASIL, 1973). This is caused by the relatively high content of organic matter. Due to low contents the contribution of clay to CEC is presumably low. No exchangeable aluminum and protons were found. Thus, the base saturation was close to 100%.

Vegetation is a typical secondary forest consisting of a mixture of deciduous trees with 12 main species and about 50 other species with smaller frequency. The stand is surrounded by soybean fields and large pastures. So it was used by the cattle as a refuge against sun and wind which is quite typical for this region. Considering fenced and open areas within the stands a strong influence of the cattle on the vegetation is obvious. Furthermore there are indications on a fire some decades ago. The estimated age of the trees is 70 yrs. Thus, most of these stands are strongly influenced by human impacts and far away from undisturbed succession forests.

Biomass and nutrients inventory was concentrated on 14 main species. Considering the diameter variation on the site, five diameter classes were established and the number of trees in each class was determined on 12 plots (10 m x 10 m). Biomass was calculated by the correlations between stem diameter and tree biomass (VOGEL et al., 2008). The correlation was determined by harvesting 20 trees from different diameter classes. Trees were partitioned into stemwood, bark, branches, and leaves. All compounds were weighted in the field immediately after harvesting. Dry biomass was calculated in the laboratory based on mean water contents.

For to quantify the contribution of the atmospheric deposition to the compensation of nutrient losses by harvesting and burning open land bulk precipitation was analyzed during a time period of five years. Samples of bulk precipitation were collected every fortnight and the concentrations of NO_3^-N, NH_4^-N, PO_4^-P, K, Ca and Mg were analyzed.

Results and discussion

Biomass stock

Mean total biomass is 210 Mg ha^{-1} (Table 2). Compared with other investigations in succession forests of South Brazil, the biomass supply is on the same level (BRUN, 2004; CALDEIRA, 2003). Higher amounts were found by Golley et al. (1975) in the humid regions of Panama. This holds even true for forest ecosystems in temperate regions of Europe with stands of Norway spruce or beech where biomass supplies totaled up to 313 Mg ha^{-1} (OTTO, 1994; SCHULTZ, 1995). However, regarding to the real growth potential of the site biomass supply is very low. In plantations of *Eucalyptus*, Black-wattle or Pinus species biomass is even higher with an age of trees less than 10 years. In an eigth years-old Eucalyptus-plantation close to Itaara biomass was already 205 Mg ha^{-1} (WITSCHOREK et al., 2003).

Table 2 – Biomass stock of tree compartments (Mg ha^{-1}).
Tabela 2 – Biomassa dos componentes das árvores (Mg ha^{-1}).

Plot No.	Stemwood	Bark	Branches	Leaves	Total biomass
1	35	5	29	2	71
2	126	15	206	8	355
3	162	19	281	10	473
4	88	11	88	5	190
5	116	14	126	6	262
6	55	7	66	3	130
7	106	14	93	6	218
8	80	10	62	4	156
9	110	14	99	6	229
10	60	8	39	3	109
11	89	11	80	5	185
12	65	8	63	4	140
mean	**91**	**11**	**102**	**5**	**210**
cv %	39	36	68	44	53

Due to the great variation of the number of individuals and the strong variation of stem diameters the biomass supply between the different plots varies in a wide range. The coefficient of variation is up to 68%, with is quite common for this type of forest.

Considering biomass distribution within the trees (Table 2) most of the biomass was accumulated in the branches followed by the trunks. This result is a rather unusual because in general trunks are the main component of the total biomass. The reason is a modified tree morphology characterized by an intensive branching in an early stage of growth caused by the influence of cattle and insects. Furthermore there was a former timber harvesting leaving the shrubs. Those were forming many shoots but no real trunks. The shoots mostly had the size of branches. The contribution of leaves to total biomass was very small. This is in accordance with a biomass inventory carried out in a secondary forest near Santa Teresa, Rio Grande do Sul (BRUN et al., 2011).

Nutrient contents of the biomass

The mean element contents of the tree compartments are shown in Table 3. According to literature (LARCHER, 1994; FIEDLER et al., 1973; RAISCH, 1983; TRÜBY, 1994), stemwood generally had the lowest nutrient contents. Stembark and branches had significantly higher contents than stemwood but mostly they were lower than those in the leaves. Ca contents of the stem bark were strongly increased. Presumably, this is caused by an accumulation of Ca-oxalate, due to an optimal or even an excessive Ca-nutrition. This is in accordance with the high Ca-saturation of the cation exchangers in the soil. In comparison with the background contents of plant material (MARSCHNER, 1995) and of leaf material from different tree species (HÜTTL, 1985; 1991) - beside phosphorus - all the nutrient contents were on a high level, indicating an excellent nutritional status.

Table 3 – Element contents of tree compartments (g kg^{-1}).
Tabela 3 – Conteúdo de nutrientes nos compartimentos das árvores (g kg^{-1}).

	N	P	K	Ca	Mg
Stemwood	3,1	0,2	2,6	3,7	1,2
Bark	12,5	0,5	4,6	24,9	2,7
Branches	9,4	0,5	5,4	12,1	2,1
Leaves	24,2	1,2	16,6	12,4	6,4

Branches were not separated to wood and bark tissue. Accordingly, the contents of the branches mostly range between those of stemwood and stembark. Only the K-contents were higher in branches than in bark. The increased K-contents of the branches – mostly taken from the upper parts of the trees - are presumably caused by the high K-demand of the physiologically active tissue in the top-tree and the corresponding K-accumulation.

Nutrient supply in the biomass

An overview about the total element supplies in the biomass and the distribution to different tree compartments is shown in Table 4. There is a wide range of element supplies varying between 80 kg ha^{-1} and 1.9 Mg ha^{-1}. Despite of the high nutrient contents, leaf-material contributes only with less than 10% to the total supply. Because of the high biomass supply, associated with high nutrient contents, branches are the main compound of the total nutrient stock in tree-biomass. Almost 2/3 of the total nutrient stock is stored in this part of the trees. Stem wood contributes only with 18 – 29 % to total amount. This corresponds with the biomass distribution in the ecosystem which is dedicated by the unusually intensive branching in this stand. Compared with other forest stands in the tropics or in moderate climates the nutrient stock in the trunks in relation to the total supply is very low (BRUN, 2011; RAISCH, 1983; TRÜBY, 1994).

Table 4 – Nutrient stock of tree compartments.
Tabela 4 – Estoque de nutrientes nos componentes das árvores.

Compartment	N	P	K	Ca	Mg
	---------------------------- kg ha^{-1} ------------------------				
Stemwood	281	17	234	338	107
Bark	143	6	52	284	31
Branches	968	51	555	1244	216
Leaves	124	6	85	63	33
Total biomass	1516	80	926	1929	387
	----------- Relative amount % -----------				
Stemwood	18,6	21,5	25,2	17,5	27,7
Bark	9,4	7,3	5,7	14,7	7,9
Branches	63,9	63,6	59,9	64,5	55,9
Leaves	8,2	7,5	9,2	3,3	8,4

The amount of nitrogen totals up to 1.5 Mg ha^{-1} which is to be assessed as a supply at the most upper range. Similar findings were made by klimo (1985) for an old stand of deciduous trees on a eutrophic floodplain soil. In contrast to this N-supply in the aboveground biomass of a one hundred years old stand of Norway spruce from Sweden was only 368 kg ha^{-1}. Following an overview of Rehfuess (1990) N-supply of old forest stands with Norway spruce and beech in Germany were varying from 353 to 796 kg ha^{-1}. In the aboveground biomass of North American coniferous forests with Douglas Fir, spruce and pinus only 315-389 kg ha^{-1} of nitrogen were accumulated (BINKLEY, 1986). In general the stock of nitrogen in forests is on a lower level than in our secondary forest from Itaara. The excellent N-status here probably results from the great number of legumes, accumulating substantial amounts of nitrogen and other nutrients.

In comparison with nitrogen and the other nutrients the stock of phosphorus in tree biomass was relatively low. However, in comparison with P-supplies from literature they are on an upper level. A similar stock of phosphorous was found in stands with Norway spruce on well- equipped sites of middle Europe. Other European stands with deciduous trees had P-supplies in the range from 38 to 92 kg ha^{-1} (DUVIGNEAUD and DENAEYER-DE SMET 1970; PAVLOV 1972). The coniferous stands from North America accumulated phosphorous only on a low level (BINKLEY, 1986).

Potassium supplies were out of the range as described in literature. In the overview of Rehfuess (1990) the maximum value was only 577 kg ha^{-1} which is around 60% of our supply.

The Calcium supply in biomass was highest of all the nutrients. Even in comparison with references from literature (BINKLEY, 1986; RAISCH, 1983, DUVIGNEAUD and DENAEYER-DE SMET, 1970) it was on the uppermost level. Almost the same amounts were found by Klimo (1985) on stands in European floodplain sediment which presumably contained carbonate. The most common range of forests on acid soils was a much lower. It was 197 to 480 kg ha^{-1}, only. In contrast to the other elements only a small percentage of the total stock was accumulated in the leafs corresponding to a high supply in the bark.

Nutrients in the soil

Total nitrogen, phosphorous and calcium contents of the soil (Table 5) are on a medium level according to those of soils with a moderate acidity or soils with substantial amounts of weatherable silicates (REHFUESS, 1990). However, potassium contents in the soil and the bedrock are high. This is presumably caused by a high stock of primary silicates as feldspar or glimmer. Compared with tropical soils as Ferralsols the contents of these elements are on a much higher level. In contrast to these nutrients magnesium contents of the soil were extremely low. The arenitic skeleton contained only traces of magnesium, close to the determination limit of the analytical method.

The contents of exchangeable K, Mg and Ca correspond with the total element contents of the soil (Table 5). Potassium and calcium are on the level of eutrophic silicate soils. Exchangeable Ca even corresponds with those of decarbonated horizons from soils on limestone (REHFUESS, 1990). Only traces of exchangeable magnesium were found. Exchangeable protons and aluminum were lower than the determination limit of the method. This is in accordance with the pH-values (Table 1) indicating only a slight acidification of the soil. Compared with soils from moderate climates e.g. Europe this is a quite different situation. Soils derived from silicate-sandstones here are commonly characterized by a stronger acidification and a much lower base saturation.

Table 5 – Total and exchangeable nutrient contents of the soil (mg g^{-1}).
Tabela 5 – Nutrientes totais e disponíveis no solo (mg g^{-1}).

Depth (cm)	Element fraction	N	P	K	Mg	Ca
		Soil fraction < 2 mm				
0-20	t	3,6	0,65	15,9	0,5	2,6
	ex	n.d.	n.d.	0,18	0,28	1,9
20-40	t	2,5	0,54	17	0,37	2,8
	ex	n.d.	n.d.	0,2	0,25	1,8
		Arenitic skeletton				
0-40	t	0	0,28	21,6	0,05	0,5

t: total content; ex: exchangeable content; n.d.: not determined

The total and exchangeable nutrient amounts of the soil (Table 6) were calculated for the fine earth < 2 mm and the skeleton of the rooted soil until a depth of 40 cm. Due to the shallow soil and the substantial amount of skeleton the supply of soil contributing to plant nutrition and internal nutrient cycling is strongly reduced. Despite of this total nitrogen and phosphorous supply was on an upper level. Similar N-amounts were found in soils with deciduous forests from South Germany, which ranged from 5,7 to 8,9 Mg ha^{-1} (BRÜCKNER et al., 1987). In accordance with the results for tree biomass it indicates a N-status on an upper level. Phosphorous stock is far away from those of soils from Cruz Alta nearby our experimental area (BRASIL, 1973). The level is in the same order of magnitude as it was found in young soils derived from silicate substrates (REHFUESS, 1990). The supply of total potassium exceeds those of the other elements by far. The potassium totals up to 46 Mg ha^{-1} indicating an unusually high stock. However, it is still in the range of silicate soils (BLUME et al., 2010). In contrast to all other nutrients the magnesium stock is extremely low. It is on the level of poor sandy soils (SCHACHTSCHABEL et al., 1992). This is primarily caused by the arenitic parent material which contains only traces of magnesium.

An overview about total nutrient supply of the whole ecosystem and the contribution of the nutrients in the biomass is shown in Table 7. The contribution of nutrients stored in the biomass to the nutrient supply of the whole ecosystem is varying in broad range. The main stock of nitrogen is stored in the soil. Nitrogen in the biomass contributes only with a relatively low percentage to total ecosystem supply. Potassium and phosphorous were also stored mainly in the soil. However related to all other nutrients the relative amount stored in the biomass for both elements is in the range from 1% to 3%, only. This is a common finding for ecosystems on silicate soils. In contrast around one quarter of total calcium and magnesium is stored in the biomass (Table 6). This is caused by a high availability of these elements in the soil. Additionally, magnesium supplies of the soil were on an extremely low level.

Nutrient input by atmospheric deposition (Table 8) is one factor that contributes to the compensation of nutrient losses by slash and burn. Nitrogen totaled up to 9,8 kg N ha^{-1} year^{-1}, which is on a relatively high level for regions with emission from industries or car traffic (FEGER, 1993). The input by ammonium is substantially higher than by nitrate, indicating that the main sources probably are emissions from agriculture. The input of the other nutrients is in the range lower than 10 kg ha^{-1} year^{-1}. This is comparable with mountainous sites from Middle Europe. The amount of phosphorous is lowest, which is a common phenomenon. The input of potassium is relatively high, although the collectors were far away from forests. Thus, it is not caused by spray from internal ecosystem cycling.

Table 6 – Soil nutrient stock (Mg ha^{-1}).
Tabela 6 – Estoque de nutrientes no solo (Mg ha^{-1}).

depth (cm)	element fraction	N	P	K	Mg	Ca
		soil fraction < 2 mm				
0-20	t	5,3	0,96	23,4	0,74	3,8
	ex	n.d.	n.d.	0,26	0,41	2,8
20-40	t	2,4	0,51	16	0,35	2,6
	ex	n.d.	n.d.	0,19	0,24	1,7
total soil <2	t	7,7	1,47	39,4	1,09	6,4
0 – 40 cm	ex	n.d.	n.d.	0,45	0,65	4,5
		skeleton				
0-20	t	0	0,1	8	0,02	0,2
20-40	t	0	0,8	20,3	0,05	0,7
total skeleton 0 -40		0	0,9	28,3	0,07	0,9
total soil 0 – 40 cm	t	7,7	2,37	67,7	1,16	7,3

t: total content; ex: exchangeable content, n.d.: not determined

Table 7 – Nutrient distribution in the whole ecosystem.
Tabela 7 – Distribuição dos nutrientes no ecossistema.

Compartment	N	P	K	Ca	Mg
	Mg ha^{-1}				
Tree biomass	1,5	0,08	0,9	1,9	0,39
Soil total	7,7	2,37	67	5,4	1,16
Total ecosystem	9,2	2,45	68	7,3	1,55
Relative amount %*of nutrients in tree biomass	16	3	1	26	25

* % of total ecosystem supply

Table 8 – Mean annual nutrient input by open land precipitation.
Tabela 8 – Médias anuais de entrada de nutrientes pela precipitação.

Input	NO_3-N	NH_4-N	PO_4-P	K	Ca	Mg
	kg ha^{-1} year^{-1}					
Open land bulk precipitation	2,7	7,1	1,2	8,7	3,9	0,9

The investigation focused on an ecological risk assessment of slash and burn forestry as it is practiced in the state of Rio Grande do Sul in South Brazil. Compared with sites in the tropics on other continents or even with the tropical regions of Brazil there are significant differences. This holds true especially for sites in the humid tropics or large areas of central Brazil covered with strongly weathered Ferralsols. Due to high precipitation and high temperatures in the humid tropics the nutrient leaching potential is high. Most of the deeply weathered soils are characterized by a low CEC and small supplies of nutrients. Accordingly, slash and burn on these sites is associated with a great risk of soil degradation (HERRERA et al., 1981; JORDAN, 1986). The site conditions of our experimental area in Rio Grande do Sul are totally different and not comparable with this situation. Considering annual precipitation and mean annual temperature of our site, a relatively small seepage rate < 300 mm $year^{-1}$ is to be expected. Hence the risk of nutrient leaching is much smaller.

The risk of nutrient loss is associated with the liberalization of nutrients by burning the biomass. Assuming the worst case that the total stock of nutrients was liberalized, leached or extracted by harvesting crops the loss of magnesium and calcium was up to quarter of the total ecosystem nutrient stock during only one rotation period. Nitrogen loss would be in the range of 16% only. In contrast to these nutrients the loss of phosphorous and potassium was negligible.

Considering the amount of exchangeable cations as a reference depending on the element high percentages could be taken up during one rotation period. In accordance the plant available magnesium and calcium stock of the soil would be emptied completely after the second repetition, the stock of exchangeable potassium even within the next one. However, this is disproved by the actual situation in the region indicating a vigorous growth of the secondary vegetation even on the sites with repeated clear-cuts. The conclusion is that nutrient loss by slash and burn is much lower than assumed with the worst case scenario.

One reason for the reduced loss of nutrients is to be seen in the incomplete burning of the biomass. Because of a missing mechanization and missing infrastructure for transportation of heavy timber old trunks often remained in the system. Especially on the steep slopes or other places where a manual extraction of timber is difficult lots of burned trunks can be found. The surface of the trunks was transformed to charcoal conserving the stems against a fast decomposition. The stock of nutrients in these stems can be assessed as a long-lasting source of nutrients well preserved against leaching.

Concerning the leaching of nutrients from the ecosystem, soil properties play a major role. Beside other leaching of nutrients is strongly affected by the soil acidity. The pH-values in our soil are close to neutral point. This is the range of the natural soil acidification caused by carbonic acid. However, when increasing the soil acidity e.g. by extracting biomass, aluminum becomes the most frequent exchangeable cation competing with the nutrient cations for the exchange sites in the soil and at the root surfaces. In our soil the base saturation was 100% indicating the absence of aluminum and an excellent nutrient availability regarding to calcium, magnesium and potassium. Compared with most of the tropical soils this is a completely different situation.

Burning is always associated with an alkalinization of the soil causing an increase of the CEC and an immobilization of elements forming hardly soluble hydroxides. This leads to a reduced leaching of calcium and magnesium after the liberalization by burning. Their oxides will be changed to hydroxides with a much lower solubility. Thus the risk of leaching is mainly for potassium which does not form hardly soluble hydroxides. It remains in a mobile plant available form associated with a high risk of leaching by infiltration water.

Because of the high base saturation exchangers are almost completely occupied by potassium, magnesium and calcium and there is only few capacity for a sorption of the elements liberalized by burning. Due to this chemical situation only a nutrient redistribution at the soil exchangers will occur and a loss by leaching is unavoidable. Because of its mobility potassium will replace magnesium and calcium from the soil exchangers after infiltration into the soil. This could cause a change in the element composition account of magnesium. Due to the small stock of exchangeable magnesium this is a certain ecological risk, if repeating slash and burn several times.

When calculating the exchangeable nutrient stock by the common methods the contribution of the skeleton was neglected completely because the analysis only uses the fine soil material < 2 mm. Thus the stock of exchangeable nutrients of the skeleton generally was underestimated for a long time. This has been shown by Heisner et al. (2004) who proved that the contribution of the skeleton to plant nutrition is substantial on sites with a low nutrient status. So the real plant available nutrient stock is higher than the calculated amounts in Table 5. Koele and Hildebrand (2008) found that root hairs and mycorrhiza fungi are able to enter fissures of stones in the soil. It was shown that the uptake from the skeleton especially on pure sandy soil was sufficient for the nutrition of Norway spruce seedlings. Thus, the real stock contributing to plant nutrition is higher than the stock of exchangeable nutrients.

Focusing on the re-establishment of the former nutrient stock the liberalization of nutrients by weathering of primary silicates is an important process. However it is proceeding very slowly and it will contribute to the recovery of the site only with some kilograms per year. If assuming a buffer rate of 0.6 $kmol_c$ ha^{-1} $year^{-1}$ (STAHR, 1979; FEGER, 1993) the liberalization of Ca, Mg and K would be in the range from 1 to 3 kg ha^{-1} $year^{-1}$. Bolte and Wulff (2001) calculated the following maximum annual weathering rates for sandy soils in northern Germany: K, 1-8; Mg, 0-34; Ca, 2-2 kg ha^{-1} $year^{-1}$. This data was used for the estimation of the ecosystem recovery (Table 10). Although the quantity is relatively small it is a permanent source causing a further shortening of the time for recovery. A special situation occurs for magnesium which is also very low in the bedrock. The liberalization would be in the range of a several hundred grams/year, only. So magnesium has to be assessed as the most problematic element in these ecosystems.

Table 9 – Mean annual nutrient input by open land precipitation.
Tabela 9 – Médias anuais de entrada de nutrientes pela precipitação.

Input	NO_3-N	NH_4-N	PO_4-P	K	Ca	Mg
	kg ha^{-1} $year^{-1}$					
Open land bulk precipitation	2,7	7,1	1,2	8,7	3,9	0,9

Table 10 – Estimated annual compensation of nutrient loss and number of years for compensation.
Tabela 10 – Estimativa anual da compensação de perdas de nutrientes e o número de anos para reposição.

Input	NO_3-N	NH_4-N	PO_4-P	K	Ca	Mg
	kg ha^{-1} $year^{-1}$					
Total atmospheric deposition*	3,5	8,6	1,2	10,9	4,9	1,2
Weathering**	0	0	n.d.	1,8	2,2	0,34
Total compensation	12,1		1,2	12,7	7,1	1,54
	Number of years for compensation					
Extraction (trunks + branches)	115		61	66	262	229
Extraction only trunks	35		19	22	87	89

* estimated by bulk precipitation and Armbruster (1998). ** estimated after Bolte and Wolff (2001).

When considering a sequence of rotations and neglecting the atmospheric input the second slash and burn would theoretically consume more as the total stock of potassium and it would reduce the plant available magnesium and calcium to 30 to 40%. Due to the huge stock of total potassium in the soil it can be assumed that there is a recovery of the exchangeable stock by weathering. Furthermore the high potassium stock in the skeleton presumably will contribute to the plant nutrition, too. Therefore a severe deficiency is not to be expected when the periods are not too short.

Even when lowering the contents of exchangeable magnesium to one third it is still adequate for plant nutrition (LIU and TRÜBY, 1989). However, any further slash and burn will bring magnesium closer to the deficiency range and in contrast to potassium the total stock is very low. Because of the smaller demand the problem is less with calcium. On the other hand a reduced amount of available nutrients is corresponding with a lower uptake rate and a lower stock of nutrients in the biomass. Accordingly nutrient loss by burning is not a linear process reducing nutrients to a zero level in a short time. The multiple repetition within short time periods will reduce the nutrient status of the site continuously. In consequence the nutrient uptake by the vegetation will decrease and with every further slash and burn nutrient liberalization and the nutrient loss will become smaller, too. According to the current situation in the region, the critical nutrient level where agriculture is not beneficial any more will not be reached after a two- or threefold repetition of slash and burn.

The current practice used in Rio Grande do Sul is associated with an extraction of wood biomass as fire wood and the complete burning of the residues which remain on the site. The extraction of timber causes an adequate loss of nutrients from the total ecosystem which depends on the intensity of harvesting. The finer the material the higher is the amount of bark, containing more nutrients than wood. Thus, the nutrient extraction increases strongly by using fine material, too. Table 8 shows the nutrient loss for the scenarios harvesting only trunks and trunks with branches, respectively. If harvesting is constrained to trunks, between 65% and 80% of the nutrients in the biomass remain in the ecosystem. However, if taking trunks and branches the percentage of nutrients remaining in the system is lower than 20%. Thus, nutrient loss can be reduced substantially by harvesting only trunks and leaving fine material in the system. This would also increase the amount of nutrients for the following agriculture.

Burning of the plant residues, the second step of shifting cultivation in this climate is necessary for the liberalization of the nutrients stored in the biomass. Mineral nutrients fixed in the organic matter are transformed to oxides firstly causing a helpful increase of the pH-value (JORDAN, 1986).

If the biomass is burnt completely, a complete liberalization of the nutrients occurs. Considering the worst case with a complete loss of all the nutrients by extracting timber, leaching and harvesting crops during the phase of agriculture substantial losses of nitrogen, calcium and magnesium would occur. Regarding to the total element supply in the topsoil calculated for the rooting zone of 40 cm up to 22% of the total stock would be lost (Table 2). In contrast to the potential loss of potassium and phosphorus would be relatively small. It ranges between 2% and 6% of the total stock in the soil. Without any further element input to the ecosystem total soil magnesium would be the element which was consumed even after repeating slash and burn four times. However, the total potassium supply in the topsoil would be sufficient for to repeat slash and burn around 40 times.

The shifting cultivation experiment in an Amazonian rainforest described by Jordan (1986) showed that most of the nutrients liberalized by burning of the biomass got lost by leaching or extraction by harvesting the crops. However, the experiment also showed that there is a recuperation process after abandoning agriculture. Presumably one reason for that is the input of nutrients from the atmosphere. However, the analysis of the bulk precipitation showed that the input from the atmosphere compared with the potential nutrient loss is relatively low (Table 4). Because of excluding the dry deposition the actual atmospheric ecosystem input is considerably higher. Thus the input rates of table 8 are minimum values.

The contribution of dry deposition to the total input is corresponding with the growth of the vegetation and the leaf area index and is varying in a broad range during the growth of the vegetation. In stands of Norway spruce in the Black Forest dry deposition contributed 25 % to total input (ARMBRUSTER, 1998). Due to the humid climate this has to be seen as a minimum value. The compensation rates in table 9 are calculated by mean weathering rates (BOLTE and WOLFF, 2001) and the atmospheric nutrient input by precipitation analysis. Because bulk precipitation is neglecting the dry deposition, it was assumed that the dry deposition is 25% of total input. Thus the estimated compensation time lasts between 61 and 262 years if extracting trunks and branches. However if the extraction is restricted to trunks the time for a compensation could be reduced strongly to a range from 19 to 89 years.

Conclusion

Slash and burn is a very common practice in Rio Grande do Sul and it is the main source of income for many people in the region. It is carried out mostly on sites with secondary forests which are not feasible for a productive mechanized agriculture.

There is no doubt that cutting and burning of these forests is the most serious intervention into these ecosystems. It is affected with substantial losses of nutrients by extracting biomass and leaching of the mobilized nutrients after burning. Considering the worst case there was a total loss of exchangeable potassium after the first repetition. However, the total stock of potassium is very high. It was enough for 40 repetitions. Because of the small stock in the bedrock a magnesium could be consumed after repeating slash and burn two or three times. So the situation for magnesium is much more serious and a deficiency is to be expected after the second repetition. For the other nutrients the problem is smaller.

It has been proved by several authors that there will be a recovery of the ecosystems after re-establishing the secondary vegetation. The stock of plant available nutrients will increase by weathering of the primary silicates and the atmospheric deposition. Neglecting the reduction of the nutrient uptake which corresponds with the decrease of the available nutrient stock and the role of plant available nutrients in the skeleton the recovery will last between 14-116 years if only trunks would be extracted and the fine material remains in the system. Generally the sustainability of this practice depends mainly of the rotation time which should be in the range of some decades. Furthermore it would be helpful to reduce the extraction of biomass to trunks. Furthermore the risk of a site degradation could be reduced if the loss of magnesium and calcium would be compensated at least partly by liming when repeating slash and burn twice or three times within short time periods.

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